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Associations between drinking-water nitrate and the productivity and health of farrowing swine

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Abstract

The associations between nitrate contained in drinking water and farrowing swine health and productivity were examined. The study was conducted from November 1989 through February 1991 on 571 randomly selected swine farms (27 207 farrowing swine) in the United States. At the beginning and end of each farm's 3-month monitoring period, the drinking water provided to the farrowing swine was tested for nitrate. Data on farrowing swine health and productivity were observed and recorded daily by the animal caretaker. Data were analyzed on a farm basis. Nitrate was detected in 53.2% (304/571) of well-water samples, with a median concentration of 2.1 ppm.

No association was seen between the nitrate concentration of drinking water and the farm litter size ($P=0.94$), proportion of the pigs stillborn ($P=0.48$), or the risk of having an above median percentage of the litter born mummified ($OR=1.0$; 95% CI 0.99, 1.00).

No association was seen between nitrate and the health of farrowing swine as measured by the risk of having an above median percentage of farrowing swine ill ($OR=1.0$; 95% CI 0.99, 1.00) or dead ($OR=0.99$; 95% CI 0.98, 1.01) due to farrowing problems, other reproductive problems (ill $OR=1.0$, 95% CI 1.00, 1.01; dead $OR=1.0$, 95% CI 0.98, 1.01), other known health problems (ill $OR=1.0$, 95% CI 0.99, 1.00; dead $OR=1.0$, 95% CI 0.99, 1.01), or unknown health problems (ill $OR=1.0$, 95% CI 0.99, 1.01; dead $OR=1.0$, 95% CI 0.99, 1.01).

The results of this study indicate that nitrate contained in drinking water, at the concentrations seen during the National Swine Study, is not associated with the farrowing swine health or productivity parameters studied.

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1. Introduction

Nitrate affects both animal (Bruning-Fann and Kaneene, 1993a) and human (Bruning-Fann and Kaneene, 1993b) health. While the effects of acute nitrate toxicosis have been well described, the effects of chronic, low-dose exposure are unclear. In humans, two studies found the consumption of drinking water from wells containing approximately 15 ppm nitrate to be associated with congenital malformations, and suggested nitrate contained in the water may have been responsible (Scragg et al., 1982; Dorsch et al., 1984). However, a review of nitrate in regard to teratogenic effects concluded that no such association has been shown (Fan et al., 1987). Some animal studies found decreased conception rates (Davison et al., 1964) and increased stillbirths (Sleight and Atallah, 1968) attributable to nitrate, while other studies reported no effect of nitrate on the maintenance of pregnancy (Eppson et al., 1960; Winter and Hokanson, 1964; Davison et al., 1965) or on birth weights (Eppson et al., 1960; Davison et al., 1965). In rats, high levels of nitrate (3000 mg l^{-1}) in drinking water have been associated with thinning and dilation of coronary arteries (Shuval and Gruener, 1972). In addition, nitrate in the ration (5.0% w/w dry food) (De Saint Blanquat et al., 1983) and in drinking water (400 ppm) (Kahraman, 1988) has been linked to decreased immune response in rats and chickens (4.2 g kg^{-1} diet) (Atef et al., 1991).

Relatively little is known about the effects of nitrate in swine. Gastritis and death have been observed in pigs from the oral administration of KNO_3 at 3.78 g kg^{-1} (Gwatkin and Plummer, 1946). Abortion, stillbirths and deformities have been associated with the consumption of oat plants with a nitrate concentration of 5.52% (Case, 1957). Nitrate ingestion has been linked to reduced weight gain (Tollett et al., 1960) and decreased liver storage of vitamin A in some studies (Koch et al., 1963; Garrison et al., 1966; Wood et al., 1967) but not in others (Seerley et al., 1965; Anderson and Stothers, 1978).

Conflicting results were also reported concerning the effects of nitrate on farrowing swine productivity. Garner et al. (1958) reported a decrease in the number of strong pigs born and their ability to survive when sows were given 2% potassium nitrate in their rations. However, Tollett et al. (1960) found no effect on corpora lutea number, percent implantation, ovary weight, embryo weight or placenta weight when up to 3.17% nitrate was added to the ration of gilts, and Seerley et al. (1965) reported no difference in litter size or average birth weight of pigs when sows were given drinking water containing up to 300 ppm nitrate.

Nitrate levels in groundwater are increasing (Vigil et al., 1965; Shuval and Gruener, 1972; Fraser and Chilvers, 1981; Holländer and Sander, 1987; Møller et al., 1989), thereby increasing nitrate exposure among those consuming water from this source. With the controversy surrounding the effects of nitrate, it is essential to establish the importance of nitrate exposure via drinking water to health.

The objective of this study was to determine if nitrate, at the concentrations observed in well water on swine farms during the National Swine Study, is associated with the productivity or health of farrowing swine. More specifically, the aim was to determine whether the nitrate content of drinking water is associated with farrowing swine productivity as measured by farm litter size, farm percentage of pigs stillborn, and farm percentage of pigs born mummified. Also, the study investigated whether the level of nitrate in drinking water is associated with farrowing swine health as measured by the percentage of swine on each farm ill or dead due to farrowing problems, reproductive problems other than farrowing, other known health problems (problems recognized by the animal caretaker that are not diarrhea, respiratory problems, lameness, farrowing problems, or other reproductive problems), and unknown health problems.

2. Materials and methods

2.1. National Swine Survey

The data used in this report were derived from the National Swine Survey (NSS) conducted by the United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service, Veterinary Services, National Animal Health Monitoring System (NAHMS) from November 1989 through February 1991. The NSS was conducted on swine farms located in 18 states (Alabama, California, Colorado, Georgia, Iowa, Illinois, Indiana, Maryland, Michigan, Minnesota, Nebraska, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Virginia and Wisconsin), which contained 62% of all swine operations and 81% of all hogs in the United States. Further information on the NSS is contained in the NSS technical report (United States Department of Agriculture, Animal and Plant Health Inspection Service, 1992).

The NSS was a large hybrid epidemiologic study utilizing retrospective, prospective and cross-sectional study designs. Individual swine farms were monitored for 3 months with the start of surveillance staggered throughout the year so that approximately equal numbers of farms were monitored during each month of the study year.

Potential study participants were identified by the USDA's National Agricultural Statistics Service (NASS). Farm eligibility criteria accounted for differences in average herd sizes among the states. In states with small average herd sizes (Alabama, California, Colorado, Maryland, North Carolina, Oregon, Pennsylvania and Virginia), farms with one or more sows or gilts expected to farrow during the study period were eligible. In the remaining 10 states, farms were eligible if ten or more sows or gilts were expected to farrow during the study period.

Swine farms were selected by NASS using a multiple-frame sampling technique. This consists of using both list (sample from a roster of all eligible units) and area frames (all eligible units in a defined geographical area are sampled) to select farms. Further information on the sampling procedure used in the NSS is contained in the NSS technical report (United States Department of Agriculture, Animal and Plant Health Inspection Service, 1992). Randomly selected farms were initially contacted by NASS personnel and the NSS explained. Out of 3184 farms initially selected by NASS, 2962 were contacted and met the criteria for eligibility in the NSS. Of the eligible farms, 1690 (53.1%) expressed an interest in participating in the study.

These 1690 farms were then contacted by federal and state regulatory veterinarians associated with the NSS and again their eligibility and interest in the study was determined.

Of the 1561 farms that remained eligible to participate, 815 began the study and 712 farms completed it. For the present analysis, 141 farms were excluded because a water source other than a well was used ($n = 106$) or because two well-water samples from the same well were not obtained ($n = 35$). Data from 571 swine farms were utilized in this investigation.

2.2. Data collection

Personnel associated with the NSS (NASS personnel and veterinarians) were trained prior to the first farm visit. During the initial visit to each swine producer, NASS personnel completed a General Swine Farm Report ascertaining current management practices and other descriptive farm information. Farms whose operators agreed to participate in the NSS were assigned to Federal and State veterinarians. These veterinarians visited the farms on a monthly basis to collect the farrowing diary cards and administered three more questionnaires.

On farms expecting less than 100 farrowings during the 3 month monitoring period, all farrowing swine were monitored; on farms expecting 100 or more farrowings, only sows and gilts entering selected farrowing units were monitored. USDA, APHIS, NAHMS staff selected farrowing units to be monitored using simple random sampling with a table of random numbers.

A Farrowing Diary Card was completed for each monitored sow or gilt and her litter. On these cards, the animal caretaker recorded all birth events, health events and preventive practices as they occurred. Cases of illness or death were classified into one of eight broad health problem categories. Cards were initiated for each sow or gilt in the monitored farrowing facility at the start of the farm's monitoring period and for each sow or gilt that entered the monitored facility during that period. Only swine that entered the farrowing facility, farrowed and weaned their litters during the farm's 3-month monitoring period are included in this analysis.

2.3. Water sampling

Water samples were collected by veterinarians at the beginning and end of the farms monitoring period (approximately 3 months between samples). Samples from the water supply that served the farrowing unit were collected as close to the point of water consumption as possible. Pipes were flushed by running the water for at least 1 min prior to sampling. All samples were shipped by priority mail (delivery by the second day) to the USDA's National Veterinary Services Laboratories (NVSL), Ames, Iowa for analysis. The farm concentration of each water-borne substance was obtained by averaging the results of the two water samples.

2.4. Laboratory testing of water

Water samples were analyzed by the NVSL for 18 different elements and compounds (United States Department of Agriculture, Animal and Plant Health Inspection Service, 1992). For the present study, only nitrate, nitrite, ammonia, and barium were considered to be potential confounders/effect modifiers and were included in analysis. Nitrate, nitrite, and ammonia were measured with an ion chromatograph while an inductively coupled argon plasma emission spectrophotometer was used to measure barium. Calibration standards were included at the beginning and end of every batch, and control samples with known ion concentrations were analyzed after every ten samples. In cases where the values were extremely high or the results were in question, the analyses were repeated.

2.5. Data analysis

2.5.1. Outcome variables (measures of health and productivity)

Using the farm as the unit of comparison, various outcome measures were calculated in order to assess farrowing swine productivity and health. Indicators of swine productivity were: farm litter size, farm percentage of pigs stillborn, and farm percentage of pigs born mummified. Farm litter size was calculated by dividing the total number of pigs born by the number of swine which farrowed. Farm percentage of pigs stillborn (or born mummified) was calculated by dividing the total number of pigs stillborn (or born mummified) by the total number of pigs born. The variable 'farm litter size' met the assumptions required for multiple linear regression while the other outcome variables did not. The variables 'percentage of pigs stillborn', and 'farm percentage of pigs born mummified' were dichotomized (as above median (over 0) or not (0)) prior to analysis using multiple logistic regression.

Indicators of farrowing swine health are the percentage of swine on each farm ill or dead due to each of the following categories: farrowing problems; reproductive problems other than farrowing; other known health problems (problems recognized by the animal caretaker that are not diarrhea, respiratory problems, lameness, farrowing problems, or other reproductive problems); and unknown health problems. For each category, the percentage of farrowing swine ill (or dead) was calculated by dividing the number of sows or gilts which became ill (or died) by the total number of sows or gilts monitored during the 3-month monitoring period. These variables were dichotomized (as above median (over 0) or not (0)) prior to analysis using multiple logistic regression.

2.5.2. Independent variables

The association between nitrate contained in drinking water and farrowing swine productivity and health was examined utilizing nitrate as both a continuous and as a binary variable (less than 45 ppm, 45 ppm or over). To quantify the unconfounded impact of nitrate on the various measures of swine health and productivity, other factors presumed likely to influence the dependent variables were statistically controlled. A review of the literature suggested that in addition to nitrate, a number of other factors might affect farrowing swine productivity or health (National Academy of Sciences–National Research Council, Subcommittee on Nutrient and Toxic Elements in Water, 1974; Leman et al., 1986; Fraser et al., 1990). Potentially confounding and/or effect modifying variables are the levels of ammonia, barium and nitrite in the drinking water; the total number of swine on the farm; the number of continuous years the farm has been involved with swine production; and the farm average sow parity. Additional variables include how the farrowing unit was managed (all-in all-out or continuous farrowing); whether the farrowing swine herd was vaccinated against *Actinobacillus pleuropneumonia*, atrophic rhinitis, parvovirus, leptospirosis, pseudorabies, *Escherichia coli*, rotavirus, *Clostridium perfringens*, erysipelas, transmissible gastroenteritis, or other diseases; the use of antibiotics in the farrowing feed; and whether anthelmintics are administered to the farrowing swine.

2.5.3. Statistical analysis

The relationships between the independent and dependent variables were examined through Spearman correlations and univariable logistic regression (Statistical Analysis Systems (SAS) Institute Inc., 1988, 1990). To control for confounding, those independent variables with a significant relationship ($P \leqslant 0.2$) to any of the 11 health or productivity outcomes were included in stratified analysis and multivariable regression (Maldonado and Greenland, 1993).

Stratified analysis was performed to assess effect modification. Because only 25 farms had nitrate levels of at least 100 ppm—the recommended limit for consumption of drinking water by livestock (United States Environmental Protection Agency (EPA), 1973)—the limit for human drinking water of 45 ppm was used during stratified analysis when control variables were included. The association between nitrate concentration in well water and decreased swine productivity was assessed as the odds ratios for (1) below-median farm litter size or not, (2) above-median farm percentage stillborn or not, and (3) above-median farm percentage born mummified or not. Similarly, the association between nitrate and swine health was measured by the odds ratios for above-median percent illness and mortality for each of the categories.

It was difficult to control for more than a few variables with stratified analysis due to vacant cells, so multivariable logistic and linear regression procedures were applied. The associations between nitrate (continuous variable), farm litter size, and the percentage of the litter stillborn were examined using multiple linear regression (SAS Institute Inc., 1988). The association between nitrate and the remaining outcome variables was examined using multiple logistic regression (SAS Institute Inc., 1990).

There is a theoretical objection to the use of linear regression with proportions. Proportions have a theoretical range of 0–1 while a regression line is theoretically unbounded. Thus, it is theoretically conceivable for a regression model to give estimates beyond the range possible for proportions. This motivated the transformation of variables measured as proportions so that the transformed variables now have a theoretical range of minus infinity to plus infinity (instead of 0–1) thus alleviating this theoretical consideration. Prior to linear regression, the variable farm percentage of stillborn was transformed to a logit using the following formula

$$\text{Logit} = \frac{\log(\text{farm percentage stillborn} + 0.01)}{1 - (\text{farm percentage stillborn} + 0.01)}$$

For use in logistic regression, the farm percentages of mummies and swine ill or dead for each category were dichotomized as being above the median or not. The statistical power of this study was derived from the tables published by Cohen (1988) for linear regression and those by Hsieh (1989) for logistic regression. Adjustment for covariates in logistic regression either has no effect or results in a loss of precision (Robinson and Jewell, 1991). The greater the correlations among covariates, the larger the sample size must be to achieve the same level of power. Because the amount of correlation between covariates in this study was small (see results below), no modification of these tables was deemed necessary. Because so many of the well samples had levels of nitrate below detection limits, the analyses were repeated using only those farms with detectable nitrate in the drinking water.

3. Results

Data from a total of 27 207 sows and gilts on 571 farms in 18 states were used in this analysis. Tables 1 and 2 describe selected characteristics of the swine farms which were used in these analyses and the general state of farrowing swine productivity and health on these farms. Nitrate was detected in 53.2% (304/571) of the well-water samples; the median was 2.1 ppm. Nitrate levels exceeded the EPA's maximum concentration of 45 ppm for human drinking water in 12.1% (69/571) of the wells sampled. In the series of analyses using only those farms with detectable levels of nitrate, the mean concentration of nitrate was 33.5 ppm and the median 17 ppm.

Significant correlations ($P \leqslant 0.05$) were observed between nitrate and several other variables (ammonia, nitrite, the total number of swine on the farm and vaccination against atrophic rhinitis and pseudorabies). The largest correlation (ammonia) was -0.25. The relatively small correlations seen and negative collinearity diagnostics (e.g. tolerance, eigenvalues) suggest that multicollinearity among the independent variables was not a problem.

Table 1
Selected characteristics of 571 swine farms: National Swine Survey, 1989–1991

Variable	25th percentile	Median	75th percentile	Range
Total number of swine	330	787	1479	3–174735
Years of swine farming	11	20	33	0–150
Average sow parity[a]	2.1	3.0	3.5	1–11
Nitrate (ppm)	0	2.1	18.5	0–460.6
Nitrite (ppm)	0	0	0	0–18.9
Ammonia (ppm)	0	0	0	0–18.9
Barium (ppm)	0	0	0	0–1.8
Farm litter size	9.7	10.5	11.2	5–16.2
Percentage stillborn	4.3	6.3	8.6	0–50
Percentage mummified	0.2	0.8	1.6	0–66.7
Illness—farrowing (%)	0	0	1.7	0–100
Illness—other reproductive (%)	0	0	0	0–63.9
Other known illness (%)	0	0	0	0–25
Unknown illness (%)	0	0	0	0–76.8
Mortality—farrowing (%)	0	0	0	0–20
Mortality—other reproductive (%)	0	0	0	0–7.7
Mortality—other known cause (%)	0	0	0	0–10
Mortality—unknown cause (%)	0	0	0	0–4.6

[a] $N = 546$ farms.

Table 2
Prevalence of selected practices on 571 swine farms: National Swine Survey, 1989–1991

Variable	%
Vaccination	
Actinobacillus	9.5
Atrophic rhinitis	45.2
Parvovirus	69.5
Leptospirosis	77.8
Pseudorabies	22.2
E. coli	52.9
Rotavirus	18.9
Clostridium	26.3
Erysipelas	68.7
Transmissible gastroenteritis	29.9
Other disease	18.7
Type of farrowing	
All-in all-out	55.5
Continuous	44.5
Use of antibiotics in farrowing feed	41.2
Use of anthelmintics in the farrowing herd	86.2

Table 3
Summary of unadjusted stratified analysis of detectable levels of nitrate, nitrate at least 45 ppm and nitrate at least 100 ppm on farrowing swine productivity and health: National Swine Survey, 1989–1991

Variable	Nitrate ≥ 45 ppm[a]		Nitrate ≥ 100 ppm[b]	
	OR	*CI*	*OR*	*CI*
Farm litter size below median	0.86	0.52–1.42	1.55	0.69–3.48
Percentage stillborn above median	0.80	0.48–1.33	0.55	0.24–1.26
Percentage mummified above median	0.98	0.59–1.62	0.79	0.35–1.76
Any farrowing illness	0.71	0.41–1.26	0.39	0.14–1.11
Any other reproductive illness	1.29	0.68–2.42	0.66	0.19–2.22
Any other known illness	0.62	0.28–1.40	0.49	0.12–2.07
Any unknown illness	0.93	0.47–1.85	1.25	0.46–3.41
Any farrowing mortality	0.69	0.27–1.79	–[c]	–
Any other reproductive mortality	1.47	0.32–6.79	–[c]	–
Any other known mortality	0.89	0.34–2.31	0.99	0.23–4.35
Any unknown cause mortality	1.04	0.30–3.59	2.07	0.47–9.07

[a]Reference to exposure to nitrate less than 45 ppm.
[b]Reference to exposure to nitrate less than 100 ppm.
[c]Unable to calculate owing to zero cell.
CI, 95% confidence interval.

Table 4
Summary of adjusted stratified analysis for the association between a nitrate level of at least 45 ppm and the percentage of mummies: National Swine Survey, 1989–1991

Control variable		OR_1	OR_2	OR_3	OR_4	OR_s	Mantel–Haenszel		Breslow–Day	
							X^2	P	X^2	P
None	–	–	–	–	–	0.98*	0.01	0.94		
Ammonia	–	1.01	0.47	–	–	0.94	0.07	0.80	0.78	0.38
$Barium_a$	–	1.02	0.94	–	–	0.98	0.01	0.93	0.03	0.87
$Barium_b$	–	1.02	0.81	1.13	–	0.97	0.02	0.90	0.26	0.88
Total swine	2.00	0.96	0.95	1.16	1.03	0.01	0.91	0.32	0.96	–
Avg. parity	0.99	0.94	0.82	5.00	1.01	0.01	0.95	2.36	0.50	–
Type farrow	1.08	0.91	–	–	0.99	0.01	0.98	0.10	0.75	–
Avg. litter size 0.86	1.10	–	–	0.96	0.02	0.89	0.24	0.62	–	–
Atrophic rhinitis	1.03	0.94	–	–	0.99	0.01	0.96	0.03	0.87	–

OR_s, summary odds ratio, *crude odds ratio. The variables are categorized as: ammonia $(0, >0)$; $barium_a$ $(0, >0)$; $barium_b$ $(0, >0$ to $<0.2, \geq 0.2)$; total swine $(\leq 49, >49$ to $\leq 300, >300$ to $\leq 1{,}000, >1000)$; farm parity $(<2, \geq 2$ to $<3, \geq 3$ to $<5, \geq 5)$; type of farrowing (all-in all-out, continuous); average litter size as $(>10.5, \leq 10.5)$; vaccination as (not vaccinated, vaccinated).

Table 5
Summary of the results of multiple linear regression models[a] for the effect of nitrate on sow productivity: National Swine Survey, 1989–1991

Variable	Coefficient	Standard error	Coefficient P-value	F-value	P-value	R^2
Avg. litter size	−0.00	0.00	0.94	1.76	0.07	0.01
Percentage stillborn	−0.00	0.00	0.48	1.78	0.11	0.01

[a]Included in these models are all covariates found to be associated $(P \leq 0.2)$ with the outcome variables.

Table 6
Summary of the results of multiple logistic regression models[a] for the effect of nitrate on sow productivity and health: National Swine Survey, 1989–1991

Variable	b	P-value	OR	95% CI
% mummified	−0.00	0.55	1.00	0.99, 1.00
% illness—farrowing	−0.00	0.67	1.00	0.99, 1.00
% illness—other reproductive	0.00	0.20	1.00	1.00, 1.01
% other known illness	−0.00	0.31	1.00	0.99, 1.00
% unknown illness	0.00	0.90	1.00	0.99, 1.01
% Mortality—farrowing	−0.01	0.29	1.00	0.98, 1.01
% mortality—other reproductive	−0.00	0.75	1.00	0.98, 1.01
% mortality—other known cause	−0.00	0.56	1.00	0.99, 1.01
% mortality—unknown cause	0.00	0.87	1.00	0.99, 1.01

[a]Included in these models are all covariates found to be associated $(P \leq 0.2)$ with the outcome variables.

The unadjusted odds ratios for the various measures of swine health and productivity on farms exposed to a nitrate level of at least 45 ppm, and to a nitrate level of at least 100 ppm relative to farms with levels below these cut-points, are displayed in Table 3. No significant differences in swine health or productivity were observed.

All outcomes were tested for effect modification using the Breslow–Day statistic (Breslow and Day, 1980). An example of our results with this procedure can be seen in Table 4 which contains a summary of the stratified analyses for the association between nitrate and the percentage of mummies adjusted for various control variables. With all outcomes and all potential effect modifiers, the Breslow–Day statistic was not significant (data not shown, available upon request). The Mantel–Haenszel approach was used to provide adjusted summary odds ratio estimators. These estimates did not significantly differ from the unadjusted odds ratios, thereby providing no evidence of confounding.

Multiple linear regression models did not reveal any association between nitrate contained in drinking water and swine productivity as assessed by the farm litter size, or percentage of the litter stillborn (Table 5). Similar results were seen when only those farms with detectable levels of nitrate were utilized in the models (data not shown, available upon request).

Multiple logistic regression revealed no association between nitrate and the risk of a farm experiencing an above median percentage of the litter born mummified (Table 6). No association was seen with the health of swine as measured by the risk of a farm experiencing above median farrowing swine illness or death due to reproductive problems other than farrowing problems, other known health problems, unknown health problems, and death due to farrowing problems (Table 6). Similar results were seen in the series of analyses utilizing only those farms with detectable levels of nitrate (data not shown, available upon request).

The study had 90% power (at $\alpha = 0.05$) to detect a partial R^2 of 0.03 for an association between nitrate and farm litter size or percent stillborn. With a sample size of 571, an odds ratio for an association between nitrate and illness due to farrowing problems as low as 1.3 could have been detected (if one existed) at $\alpha = 0.05$ with a statistical power of 80%. Statistical power was sufficient to have detected an odds ratio (at $\alpha = 0.05$, $\beta = 0.20$) as low as 1.4 for illness due to reproductive, known, or unknown problems; 1.5 for death due to farrowing or known problems; 1.8 due to unknown problems; and 2.5 for death due to reproductive problems.

4. Discussion

The NSS was a large swine study designed to reflect the swine population and swine farms of the US. However, not all swine farms initially selected for the study chose to participate. A comparison of respondents versus nonrespondents, based on data previously reported to NASS regarding herd size, litter size, and litter mortality, revealed no significant differences with regard to litter size or mortality (United States Department of Agriculture, Animal and Plant Health Inspection Service, 1992). However, both total herd and farrowing herd sizes were larger among NSS participants compared with nonparticipants. Therefore, herd sizes reported with the NSS are larger than those which would have been reported, had all selected farms chosen to participate.

Investigators have reported dystocia rates of 2.9% (103 farrowings on five farms) (Randall, 1972a), 0.25% (772 farrowings) (Jones, 1966), and 1.54–2.50% (70 farms) (Lingaas and Rønnigen, 1991) of farrowing sows. The overall farm percentage of swine ill due to farrowing problems in this investigation is 2.1%. Because this category of illness includes dystocia plus other farrowing-related problems (e.g. prolapsed uterus), this figure is not immediately comparable with other reports. However, it is likely that dystocia is by far the largest portion of farrowing related problems.

Previous studies have reported 1.8% (24/125) (Randall, 1972b) and 1.6% (228/14, 390) (Billie et al., 1974) of pigs born were mummified; 5% (67/125) (Randall, 1972b) and 4.3% (622/14, 390) (Billie et al., 1974) stillborn. Another study reported that a total of 7.6% (4366/57 195) of pigs born were stillborn or mummified (Partlow et al., 1993). These findings are similar to the farm rates of 1.4% mummified and 6.9% stillborn observed in this study. There are several differences between this report and previous studies. Previous studies were conducted in England, Canada, Norway, and Denmark and were much smaller, while this investigation was done in the US and involves 27 207 farrowings on 571 swine farms. Also, unlike the previously mentioned studies which were performed on an individual-animal basis, this study used the farm as the unit of analysis.

The presence of water samples with no nitrate detected was an impediment to statistical analysis. The occurrence of samples with values below detection limits is common in environmental water sampling and can be handled in a variety of ways (Newman et al., 1989; Hurd, 1993). In this study, values below the detection level were recorded as 0. This method will, to some extent, bias the estimate of the mean downward while increasing the estimate of the standard deviation. Also, the analyses were repeated using only those farms with detectable levels of nitrate to determine if a dose–response relationship exists between nitrate in drinking water and farrowing swine health and productivity.

Nitrate levels measured in this study exceeded the recommended limit for human drinking water (45 ppm) in 12.1% (69/571) of the well-water samples. While this concentration is higher than the estimates of 6.4% of wells by the US Geological Survey or 2.4% by the EPA (United States Department of Agriculture, 1991), it is similar to the level of 10% reported by the Monsanto Agricultural Products Company (United States Department of Agriculture, 1991). The differences in estimates of nitrate concentration in well-water may be related to the different criteria for well selection. The U.S. Geological Survey and the E.P.A. sampled household wells, whereas the NSS and the Monsanto study sampled wells on farms.

When included in multivariable analysis, nitrate was not associated with farrowing swine health or productivity. This study had adequate power to have detected even a moderate level of association with nitrate, if such an association existed.

The lack of any detectable association between nitrate and the various outcome variables suggests that the concentration of nitrate seen in well water during the NSS does not affect the health or productivity of farrowing swine as measured in this study. These findings agree with previous studies that found no effect from nitrate on sow productivity (Tollett et al., 1960; Seerley et al., 1965). A previous study linking nitrate to decreased productivity

(Garner et al., 1958) was conducted with only a small number of animals, so those results may be unreliable.

Because of the paucity of information on the effects of low levels of nitrate on swine health and productivity, further studies would serve to verify these conclusions. In addition, this study only examined the association between nitrate contained in drinking water and farrowing swine health. Further research is needed to determine the effects of nitrate on swine during other stages of production.

This study was a valuable endeavor for several reasons. The first reason was to determine if there is an association between nitrate in drinking water and farrowing swine productivity or health. This is important for both humane (welfare of the animal) and economic reasons (decreased productivity or health would increase the cost of production).

This research was also important because of the relevance of nitrate to human health. While the effects of high doses of nitrate in humans is well established, the impact of nitrate at low levels remains controversial. Among the livestock species, swine are the closest to humans in physiology (being monogastrics and omnivores). As such, swine could be used to monitor the response of humans to exposure to various agents. Thus, the finding of even a small adverse health response in swine would have served to stimulate further investigation into the possible health effects of nitrate exposure in humans.

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